# On the Model-free Control of an Experimental Greenhouse

Frédéric Lafont, Nathalie Pessel, Jean-François Balmat, and Michel Fliess

***Abstract*—In spite of a large technical literature, an efficient climate control of a greenhouse remains a very difficult task. Indeed, this process is a complex nonlinear system with strong meteorological disturbances. The newly introduced "model-free control" setting is employed here. It is easy to implement, and has already shown excellent performances in many other concrete domains. Successful experimental tests are presented and discussed. They are compared to a Boolean approach, which is often utilized in practice.**

***Index Terms*—Greenhouse, climate control, model-free control, intelligent PI controller.**

## I. Introduction

THE main objective of a greenhouse crop production (see, *e.g.*, [1]) is to increase economic benefits for the farmer when compared to more traditional techniques. An adequate regulation should not only improve the production and its quality but also reduce pollution and energy consumption. Controlling the internal hygrometry and the carbon dioxide should optimize therefore the photosynthesis. The resulting system should:

- remain open for exploiting the advantages of some external disturbances, like radiation and temperature,
- filter possible adverse conditions, like wind and rain.

There is already an enormous literature (see, *e.g.*, [2], [3]) on this important topic from an applied viewpoint. A large variety of tools has been utilized. Many studies have been devoted to obtain a "good" knowledge model. It might be

- static, and based on a thermic balance (see, *e.g.*, [4]),
- dynamic, and based on an energy balance (see, *e.g.*, [5]).

The obtained physical models are nonlinear, and strongly disturbed, *i.e.*, often by weather conditions which are impossible to forecast precisely (see, *e.g.*, [6]). Complex calibrations prevent moreover to utilize those models for writing down efficient control laws. Multi-models were also proposed (see, *e.g.*, [7], [8], [9], [10]), as well as black box models (see, *e.g.*, [7], [10], [11]). Here also it is difficult to deduce a control synthesis. Fig. 1, which is borrowed from [3], displays the most popular viewpoints. Among the "conventional" control synthesis methods, let us point out the well-known PID controllers and On/Off techniques. See also:

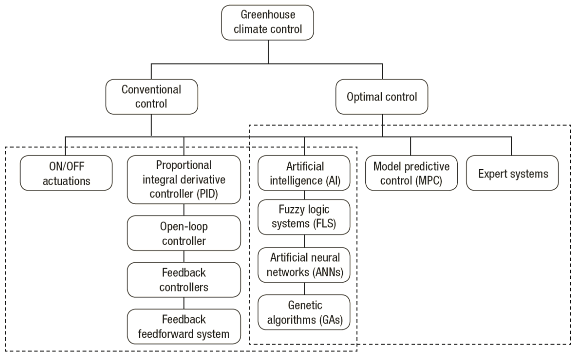


Fig. 1. Greenhouse control theories classification

- [6], [8], [9], [12], [13] for the modeling,
- [7], [14], [15], [16], [17] for the control.

This communication is devoted to the control of an experimental greenhouse via a newly introduced technique, called *model-free control* ([18], [19], [20], [21]), where the need of any mathematical model disappears. It should be emphasized that this setting, which yields easily implementable *intelligent* PID controllers, has been within a few years successfully applied in a number of practical case-studies, which cover a large variety of domains (see, *e.g.*, the references in [21], and [22], [23], [24], [25], [26], [27], [28]).

Our paper is organized as follows. Section II is devoted to a brief review of model-free control. Section III presents our experimental greenhouse system and the corresponding modeling problems. The intelligent PI controllers are implemented in Section IV. A comparison with a Boolean controller is discussed in Section V. Section VI provides a short conclusion.

## II. Model-free control: A short review

Let us restrict ourselves for simplicity's sake to single-input single-output systems.

### A. The ultra-local model

The unknown global description of the plant is replaced by the *ultra-local model*:

$$\boxed{y^{(\nu)} = F + \alpha u} \tag{1}$$

where:

- the derivation order $\nu \geq 1$ is selected by the practitioner;
- $\alpha \in \mathbf{R}$ is chosen by the practitioner such that $\alpha u$ and $y^{(\nu)}$ are of the same magnitude.

Manuscript received April $30^{th}$, 2013; revised May $31^{st}$, 2013. This work was supported by the Institut Universitaire de Technologie de Toulon, France.

F. Lafont, N. Pessel and J-F. Balmat are with LSIS (UMR CNRS 7296), Université du Sud-Toulon-Var, 83957 La Garde, France ({lafont, nathalie.pessel, balmat}@univ-tln.fr).

M. Fliess is with LIX (UMR CNRS 7161), École polytechnique, 91128 Palaiseau, France and with A.L.I.E.N. SAS, 24-30 rue Lionnois, BP 60120, 54003 Nancy, France (michel.fliess@alien-sas.com, Michel.Fliess@polytechnique.edu).

*Remark 2.1:* Note that $\nu$ has no connection with the order of the unknown system, which may even be with distributed parameters, *i.e.*, which might be best described by partial differential equations (see, *e.g.*, [29] for hydroelectric power plants).

*Remark 2.2:* The existing examples show that $\nu$ may always be chosen quite low, *i.e.*, 1 or 2. In almost all existing concrete case-studies $\nu = 1$. The only counterexample until now where $\nu = 2$ is provided by magnetic bearings [24] where frictions are almost negligible. See the explanation in [20], [21].

Some comments on $F$ are in order:

- $F$ is estimated via the measure of $u$ and $y$;
- $F$ subsumes not only the unknown structure of the system but also of any perturbation.

### B. Intelligent PIDs

Set $\nu = 2$ in Equation (1):

$$\boxed{\ddot{y} = F + \alpha u} \tag{2}$$

Close the loop via the *intelligent proportional-integral-derivative controller*, or *iPID*,

$$\boxed{u = -\frac{F - \ddot{y}^* + K_P e + K_I \int e + K_D \dot{e}}{\alpha}} \tag{3}$$

where:

- $e = y - y^\star$ is the tracking error,
- $K_P$, $K_I$, $K_D$ are the usual tuning gains.

Combining Equations (2) and (3) yields:

$$\ddot{e} + K_D \dot{e} + K_P e + K_I \int e = 0$$

where $F$ does not appear anymore. The tuning of $K_P$, $K_I$, $K_D$ is therefore quite straightforward. This is a major benefit when compared to the tuning of "classic" PIDs (see, *e.g.*, [30], [31], and the references therein).

Set now $\nu = 1$ in Equation (1):

$$\boxed{\dot{y} = F + \alpha u} \tag{4}$$

The loop is closed by *intelligent proportional-integral controller*, or *iPI*,

$$\boxed{u = -\frac{F - \dot{y}^* + K_P e + K_I \int e}{\alpha}} \tag{5}$$

If $K_I = 0$, it yields an *intelligent proportional controller*, or *iP*,

$$\boxed{u = -\frac{F - \dot{y}^* + K_P e}{\alpha}} \tag{6}$$

*Remark 2.3:* Equation (4) and the corresponding iPs (6) are most common in practice. This is again a major simplification with respect to "classic" PIDs.

*Remark 2.4:* See [20], [21], [32] for an analysis of the connections with "classic" PIDs and PIs.

Fig. 2. Our experimental greenhouse system

### C. Estimation of $F$

*1) First example:* $F$ in Equation (1) is assumed to be "well" approximated by a piecewise constant function $F_{\text{est}}$. According to the algebraic parameter identification developed in [33], [34], rewrite, if $\nu = 1$, Equation (4) in the operational domain (see, *e.g.*, [35]):

$$sY = \frac{\Phi}{s} + \alpha U + y(0)$$

where $\Phi$ is a constant. We get rid of the initial condition $y(0)$ by multiplying both sides on the left by $\frac{d}{ds}$:

$$Y + s\frac{dY}{ds} = -\frac{\Phi}{s^2} + \alpha \frac{dU}{ds}$$

Noise attenuation is achieved by multiplying both sides on the left by $s^{-2}$. It yields in the time domain the realtime estimate:

$$F_{\text{est}}(t) = -\frac{6}{\tau^3} \int_{t-\tau}^{t} \left[(\tau - 2\sigma) y(\sigma) + \alpha\sigma(\tau - \sigma) u(\sigma)\right] d\sigma$$

where $\tau > 0$ might be quite small. This integral may of course be replaced in practice by a classic digital filter.

*2) Second example:* Close the loop with the iP (6). It yields:

$$\phi = \frac{1}{L} \left[ \int_{t-L}^{t} \left(\dot{y}^\star - \alpha u - K_P e\right) d\sigma \right]$$

*Remark 2.5:* Another possibility for estimating $F$, which was employed in the first stages of model-free control, is the estimation of the differentiation of the noisy output signal $y$ (see [36], [37]).

## III. Our Experimental Greenhouse System

Fig. 2 shows our experimental plastic greenhouse which is manufactured by the French company *Richel*. Its area is equal to 80 m$^2$. It is the property of the *Laboratoire des Sciences de l'Information et des Systèmes* (*LSIS*), to which the first three authors belong.[1] This experimental greenhouse is controlled by a microcomputer and interfaced with the FieldPoint FP-2000 network module developed by the company *National Instruments Corporation*. The FP-2000 network module is associated with two analog input modules (FP-AI-110, FP-AI-111), for the acquisition, and two relay output modules (FP-RLY-420), for the control. The acquisition and control system is developed with the *LabView* language. See Fig. 3 for the control interface. The sampling period is equal to 1 minute. The inside air temperature and humidity are controlled via our techniques.

[1]This laboratory is located at the *Université du Sud-Toulon-Var*, France.

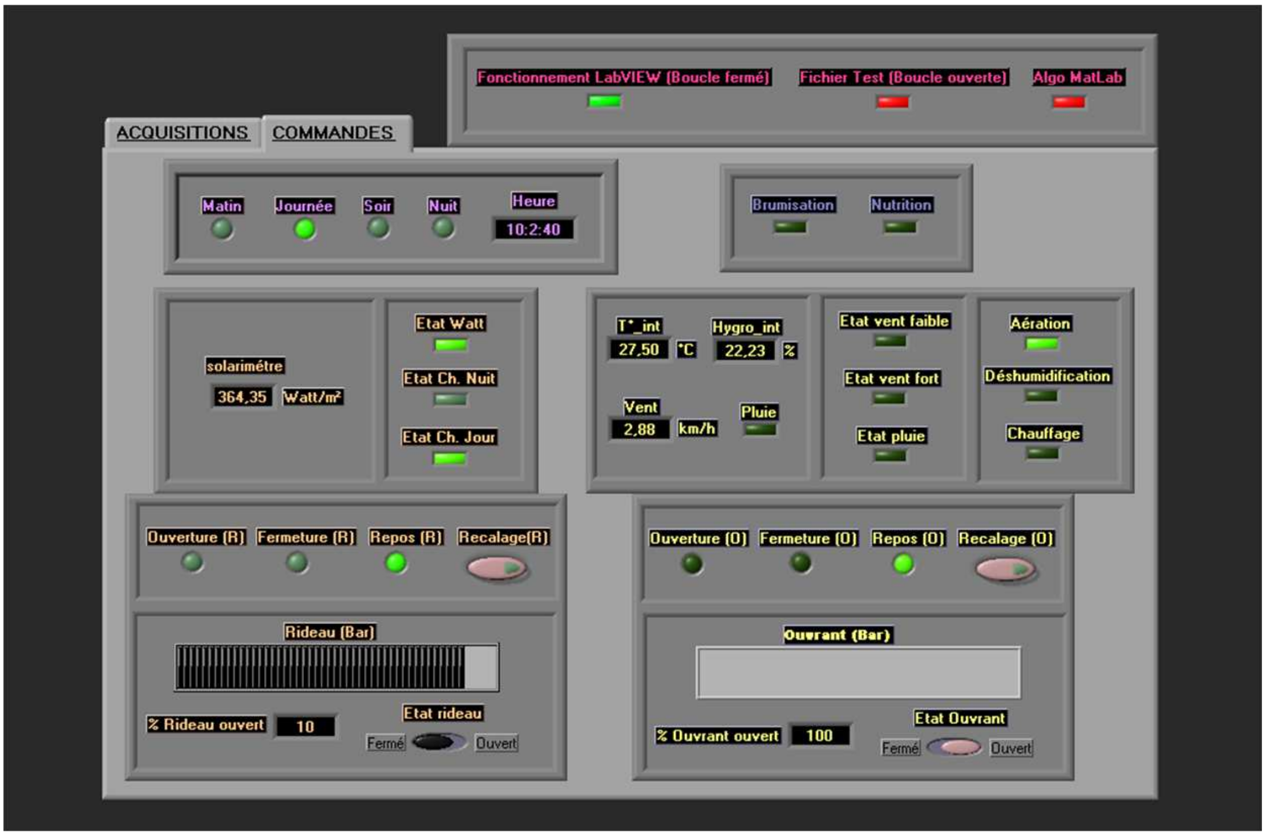


Fig. 3. Control interface

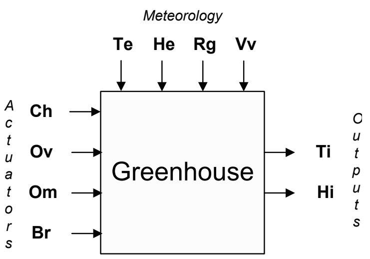


Fig. 4. System variables

### A. Description of the system

The greenhouse is a multi-input and multi-output (MIMO) system which is equipped with several sensors and actuators (see Fig. 4). There are

- 4 actuators:
  1) Heating (thermal power 58 kw): Ch ($Boolean$),
  2) Opening (50 % max): Ov (%),
  3) Shade: Om (%),
  4) Fog system: Br ($Boolean$).
- 4 meteorology disturbances sensors:
  1) External temperature: Te ($^oC$),
  2) External hygrometry: He (%),
  3) Solar Radiation: Rg ($W/m^2$),
  4) Speed of the wind: Vv ($km/h$).
- 2 internal climate sensors:
  1) Internal temperature: Ti ($^oC$),
  2) Internal hygrometry: Hi (%).

This system is moreover nonstationary and strongly disturbed.

### B. Control of temperature and hygrometry

In the greenhouse system, the temperature and hygrometry management are treated together, because these two quantities are strongly correlated:

- The heating has a dehumidifier effect.
- The opening system has a cooling and dehumidifier effect.
- The fog system has a cooling effect.

Controlling the temperature and the hygrometry is therefore of utmost importance.

*1) Hygrometry reference:* There is no real recommendations by species. It appears nevertheless that

- for the multiplication phase, the hygrometry must be greater than 80 %,
- for the growth phase, the reference is comprised between 60 and 80 %,
- for the tomato, the reference is rather comprised between 50 and 70 %.

Let us mention some other advices:

- avoid condensations,
- avoid a humidity level close to saturation (100 %),
- avoid a humidity level below 40 % for seedlings,
- absolutely avoid a hygrometry below 20 %.

*2) Temperature reference:* Table I displays references among suppliers, which are based on the species.[2] Observe

[2]The temperatures are expressed with degrees Celsius.

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

TABLE I
TEMPERATURE REFERENCE (SEE [1])

| Species | Night reference | Day reference | Remarks |
|---|---|---|---|
| Aubergine | $21^oC$<br><br>$19^oC$ | $22^oC$<br><br>$21^oC$ | During 4 weeks after the plant.<br>To the end |
| Cucumber | $21^oC$<br><br>$20^oC$<br><br>$19^oC$ | $23^oC$<br><br>$22^oC$<br><br>$21^oC$ | During 4 weeks After the plant.<br>During the next 6 weeks.<br>To the end. |
| Lettuce | $10^oC$<br><br>$6^oC$ | $10^oC$<br><br>$12^oC$ | During 2 weeks After the plant.<br>To the end. |
| Pepper | $20^oC$<br><br>$18^oC$ | $23^oC$<br><br>$22^oC$ | During 3 weeks after the plant.<br>To the end. |
| Tomato | $20^oC$<br><br>$18.5^oC$<br><br>$17.5^oC$ | $20^oC$<br><br>$19.5^oC$<br><br>$18.5^oC$ | During 1 week after the plant.<br>During the next 5 weeks.<br>To the end. |
| Azalea | $18/21^oC$ | $>18^oC$ | |
| Chrysanthemum | $17^oC$ | $18^oC$ | |
| Gerbera | $13/15^oC$ | | |
| Antirrhinum | $10/11^oC$ | | |
| Carnation | $12/13^oC$ | $18^oC$ | |
| Rosebush | $17^oC$ | $21^oC$ | |

that the difficulties for tuning an efficient controller may be attributed to the following causes:

- various references
  - in a day,
  - according to the species,
- system parameter variations according to the plant growth.

## IV. APPLYING INTELLIGENT PROPORTIONAL-INTEGRAL CONTROLLERS

Two iPIs (5) are implemented for independent regulations of the temperature and of the hygrometry. We are estimating $F$ via the technique sketched in Section II-C2.

### A. Temperature

The estimation $F_{\text{approx}}^{\text{temp}}$ is given by

$$F_{\text{approx}}^{\text{temp}} = \frac{1}{\delta}\int_{T-\delta}^{T}\Big(-\alpha Ch + \dot{Ti}^{*} - K_P e_{Ti} \\ - K_I \int e_{Ti}\Big)\, d\tau \tag{7}$$

### B. Hygrometry

Here

$$F_{\text{approx}}^{\text{hygro}} = \frac{1}{\delta}\int_{T-\delta}^{T}\Big(-\alpha Br + \dot{Hi}^{*} - K_P e_{Hi} \\ - K_I \int e_{Hi}\Big)\, d\tau \tag{8}$$

TABLE II
SETTING VALUES

| Variable | Value |
|---|---|
| $\delta$ | 12 minutes |
| $\alpha$ | 10 |
| $K_I$ | 0.1 |
| $K_P$ | 2 |

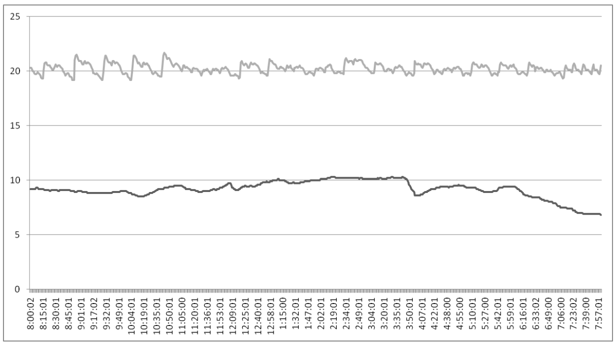


Fig. 5. Internal temperature with model-free control (Te: black line - Ti: grey line)

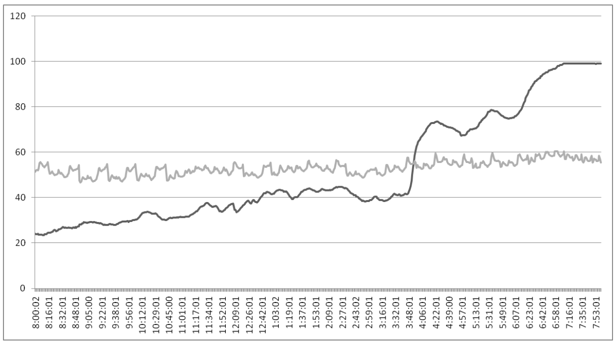


Fig. 6. Internal hygrometry with model-free control (He: black line - Hi: grey line)

### C. Setting values

The controllers $Ch$ and $Br$ are deduced from Equations (4), (5), (7), and (8). These controllers are *Pulse Width Modulation* (*PWM*) controllers. Table II displays the same setting values for the two controllers.

The reference outputs are $20^o$ for the temperature and $50\%$ for the hygrometry. The simulation lasts 12 hours, from 8:00 pm until 8:00 am. We chose the night in order to compare the obtained results with Boolean control (see Section V) in similar weather conditions. During this season in the south of France the outside temperature is moreover too hot during the day in order to reach the chosen reference inside the greenhouse.

Fig. 5 and Fig. 6 show the internal/external temperature and the internal/external hygrometry evolution on the night of March $19^{th}$, 2013.

Fig. 7 and Fig. 8 show the control sequences for heating and fog.

We can observe that, at 4:00 am, $H_e$ is close to 100 %: it started to rain. The internal hygrometry $H_i$ is also above the reference output and the fog system $Br$ stops. The heating control allows to lower and stabilize the internal humidity

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

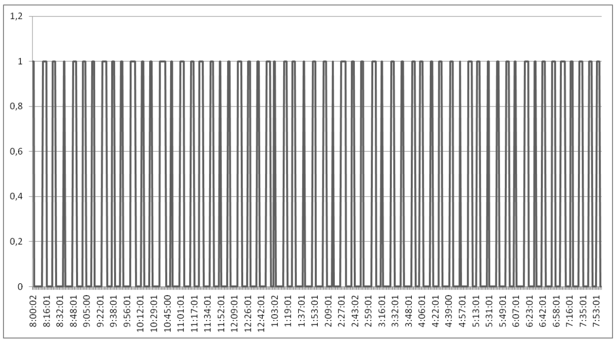

Fig. 7. Heating control with model-free control

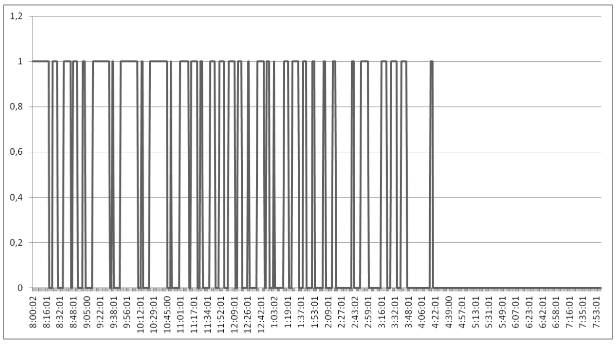

Fig. 8. Fog control with model-free control

TABLE III
RESULTS EVALUATION FOR THE MODEL-FREE CONTROL

| Output | mean | variance |
|---|---|---|
| $\epsilon T_i$ | $0.35^o$ | $0.07^o$ |
| $\epsilon H_i$ | $5.11\%$ | $6.92\%$ |

level. Finally, the internal temperature $T_i$ and the internal hygrometry $H_i$ are close to their reference output.

Table III shows the mean and the variance of the error between $T_i$ and the output reference of $T_i$ and between $H_i$ and the reference output of $H_i$.

## V. SOME COMPARISONS

A classic Boolean control law with thresholds is employed for the comparisons. This type of technique is quite often used in agriculture. Experiments have been carried on during two different nights, *i.e.*, March $18^{th}$ and $19^{th}$ , 2013, respectively for the Boolean and model-free settings. The temperature reference output is $20^o$, as in Section IV. For the hygrometry, a dehumidification reference should be selected. The fog control is periodic (3 minutes on, and 27 minutes off) whatever the internal hygrometry. This Boolean control of the humidity is based on the grower rules. The dehumidification reference allows to set the desired maximum hygrometry inside the greenhouse. In this test, we choose $50\%$.

Fig. 9 and Fig. 10 show results for the internal temperature and the internal hygrometry. Fig. 11 and Fig. 12 show results for the two controls. Fig. 9 and Fig. 10 show results for the internal temperature and the internal hygrometry. Fig. 11 and Fig. 12 show results for the two controls. Table IV

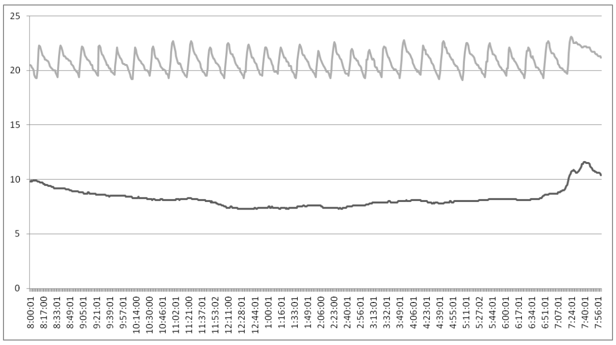

Fig. 9. Internal temperature with a Boolean controller (Te: Black line - Ti: Grey line)

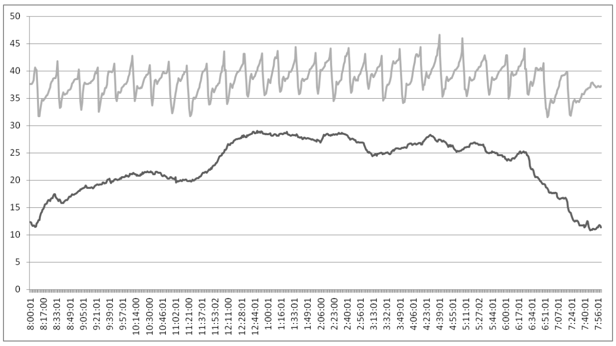

Fig. 10. Internal hygrometry with a Boolean controller (He: Black line - Hi: Grey line)

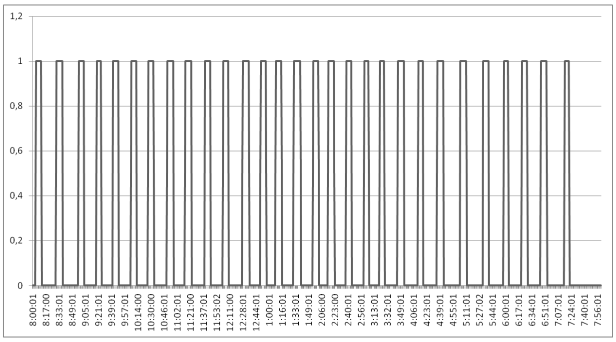

Fig. 11. Heating control with a Boolean controller

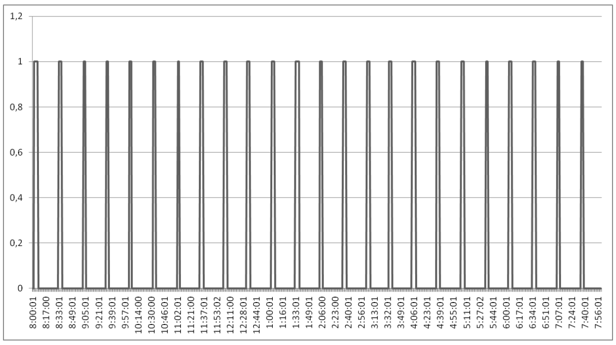

Fig. 12. Fog control with a Boolean controller

shows the mean and the variance of the error between $T_i$ and the output reference of $T_i$ and between $H_i$ and the reference output of $H_i$.

Tables III and IV demonstrate that our model-free control strategy behaves better than its Boolean counterpart. Let us

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

TABLE IV
RESULTS EVALUATION WITH A CLASSIC BOOLEAN CONTROL

| Output | mean | variance |
|---|---|---|
| $\epsilon T_i$ | $0.98^o$ | $0.57^o$ |
| $\epsilon H_i$ | $11.63\%$ | $6.62\%$ |

TABLE V
COMPARISONS OF THE ENERGY

| Actuator | Model-free control | Classical Boolean control |
|---|---|---|
| $Heat$ | 221 $min$ | 209 $min$ |

emphasize two more points:

- As already explained in Section III, one of the goals of control climate is to reduce the energy consumption. Table V shows that the heating is on only during $30\%$ of the time with the model-free setting.
- For a given operating time, model-free control ensures a better tracking of the reference signals.

## VI. CONCLUSION

This paper presents a model-free control of the climate of an experimental greenhouse. This setting turns out to be more efficient than a classic Boolean control. It is moreover much more easier to tune than a classic PID controller.
Future publications will develop our viewpoint, and compare it to several other existing approaches. They will also study fault diagnosis and accommodation (see, *e.g.*, [20], [21]), and data mining for climate control (see, *e.g.*, [38]).

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ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)